Name _____ Topics ID # _____

Team Name _____

2025 WUCT: Science Fiction Exam

April 5th, 2025
11:00 a.m. – 12:00 p.m.

Please fill in the numbers of your 6-digit topics ID:

Topics ID

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1 HOUR will be allowed for the exam. The examination contains **6** questions on **23** numbered pages, including the last **SCRATCH PAGE**.

TURN IN THE ENTIRE EXAM (INCLUDING THE SCRATCH PAGE) WHEN YOU ARE FINISHED!

Exam Points Breakdown:

1. (21 pts)
2. (15 pts)
3. (16 pts)
4. (17 pts)
5. (19 pts)
6. (12 pts)
Total Points: (100 pts)

2025 WUCT: Science Fiction Exam

This exam consists of 6 questions and is worth 100 points. You will complete this exam as a pair. You will have 1 hour to take the exam. The only allowed resources for this exam are a calculator and the provided equation sheet. You may NOT use any other notes or books. You must show your work and box your final answer to receive credit for a problem. NOTE: If you get the answer to an early part of a question incorrect but later use that answer for a subsequent part of the question, you can still earn full credit for those subsequent parts. Please write your answer in the designated space on the answer sheet. If you need additional space for a problem, you may use the blank scratch page at the end of the exam. Make sure to clearly indicate in the problem's designated space where the rest of your work can be found. Any work anywhere other than the exam or the scratch page will not be graded. Dark pencil or pen is preferred.

Problem #1: *(21 points)*

You and your team of space explorers are exploring the galaxy on a tricked out rocket! Suddenly your atmospheric scanner starts pinging, signaling that Planet Atomica is nearby. You and your team decide to explore!

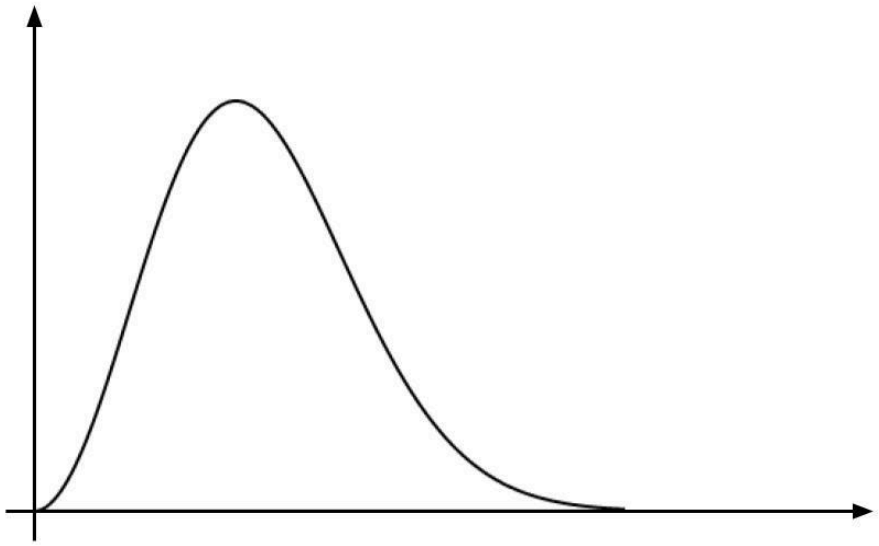
a. First, you and your team want to determine the composition of the atmosphere. You collect a 10 gram sample of the atmosphere and run it through your rocket's gas detector. It determines that Planet Atomica's atmosphere is composed of (by mass) 26% carbon dioxide, 37% methane (CH_4), and 37% **unknown diatomic gaseous compound** in a 5:20:2 molar ratio, respectively. What is the identity of the unknown gaseous compound present in Planet Atomica's atmosphere? *Hint: it is a halogen diatomic gas.* ***(4 points)***

   Unknown Diatomic Gaseous Compound Identity: _____

b. You and your team take a temperature scan of the outermost atmospheric layer and find that it is 2,000 ℃. ***(4 points)***

   i. What is the mean speed (in m/s) of the carbon dioxide molecules? Assume the gas is behaving ideally. ***(2 points)***

   ii. The following diagram is the Boltzmann distribution for carbon dioxide at room temperature (25˚C). Draw what the Boltzmann distribution would look like at 2,000 ℃. ***(2 points)***



c. The ideal gas law predicts the relationship between the temperature, pressure, volume, and amount of an ideal gas. However, real gases don't behave ideally and these deviations can be predicted using the Van der Waals equation: $P = \frac{RT}{V-b} - \frac{a}{V^2}$, where a is a constant directly related to the strength of intermolecular forces in the gas and b is a constant directly related to the **size** of the gaseous molecule (**not** its weight).

To get an idea of how the pressures on Planet Atomica and Earth differ, you decide to compare the pressures of the most abundant gases in each atmosphere: CH_4 for Planet Atomica and N_2 for Earth.

If both gases were at standard conditions, 298 K, and present in equal amounts, which gas would have the greater pressure, as predicted by the Van der Waals equation? ***(4 points)***

a. CH_4
b. N_2
c. Cannot determine

Provide an explanation for your choice.

d. To make sure your rocket will pass through the planet's atmosphere safely, you decide to reinforce the rocket's heat shield. You and your team have two options for what material to use: alumina (Al_2O_3, Specific Heat Capacity = 0.880 J/g℃) or carbon phenolic (C_6H_5OH, Specific Heat Capacity = 0.938 J/g℃). Provide a brief explanation for which material your team should use. ***(2 points)***

_____

_____

_____

_____

e. While running some computations, you accidentally spill coffee on your desk, and decide to clean it with an ethanol (C_2H_5OH) solution. The normal boiling point of ethanol is 78.3 ℃. The standard enthalpy of vaporization of ethanol is 38.56 kJ/mol. Calculate the vapor pressure of the ethanol at room temperature (25˚C). ***(4 points)***

f. Lastly before you exit the rocket, it is important to think about the reactions that could be occurring in the planet's atmosphere. At high temperatures, methane and water can react. Write out this reaction on the line provided below **and**, based on this reaction, provide a justification as to why it is important that you are equipped with your spacesuit and protective gear before you step out. ***(3 points)***

Reaction: _____

Justification:

_____

_____

_____

_____

Problem #2: *(15 points)*

Congratulations! You and your team of space explorers have successfully landed on the surface of Planet Atomica. But is it safe to leave your rocket?

a. Your space suit is capable of protecting you from UV radiation up to a photon energy of $3.62 \times 10^{-16} J$. The UV radiation emitted from the sun of Planet Atomica ranges from 600 picometers to 50 nanometers. Do your suits protect you and your team as they are, or will additional layers of protection be necessary? Show your work and circle your answer below. ***(3 points)***

The suits are fine as they are. **The suits need to be modified to be safe.**

b. Your scanners detect that the rock structures nearby are made of polonium and have an average atomic mass of 209.56 amu. Knowing how toxic it is to humans, you must investigate. Determine the isotopic abundances of Polonium-210 and Polonium-209, using the fact that the rock structures are 1.09% Polonium-208 and these are the only three isotopes present. ***(2 points)***

Polonium-210: _____ Polonium-209: _____

c. Through an elemental dating process, the rock structures are determined to be 7.8 billion Earth years old. This is 2.06×10^{10} half lives of the Polonium-210. What is the half life of Polonium-210 in Earth **days**? Round your answer to the nearest day. ***(2 points)***

d. To find how many grams of sample remain after a given number of half-lives, you must multiply the original mass by $(\frac{1}{2})^{n}$, where n is the number of half-lives.

The sample you and your team obtained of the rock structure was 65 g. Assuming that it was pure Polonium-210, how much time will have elapsed (in Earth days) when only 8% of the sample remains? ***(4 points)***

e. Before leaving the rocket, you and your team need to know how you'll be affected by gravity. You set up an electric field that points upwards and you suspend a droplet charged with the fundamental unit of charge so that the electric force experienced balances out the gravitational force on the droplet.

   If the mass of your suspended droplet is 2.8×10^{15} times larger than the mass of a proton (in kg), and the electric field needed to suspend the droplet is 8.73×10^{8} N/C, what is the gravitational constant of Planet Atomica? ***(3 points)***

f. Humans can withstand up to around 5 times the strength of Earth's gravity before facing serious health complications. Based on your answer in part (e), how many times stronger is Planet Atomica's gravity than Earth's? ***(1 point)***

Problem #3: ***(16 points)***

Now that you've determined that it's safe to exit your spaceship, it's time to research Atomica. Can this planet support human life? If not, could anyone—or anything—be living here?

a. Your team investigates the planet by collecting a sample of a nearby water source in a solid aluminum container. The container starts to rapidly dissolve and bubble, signifying the water is highly acidic! Your team identifies the dissolved remains as $AlCl_3$ and the bubbles as H_2 gas. Propose the reaction that occurred with the container. ***(2 points)***

b. Use the table provided to aid you in answering the following questions. ***(2 points)***

[H^+] Concentration (mol/L)	**pH at 25°C**	**pH at 80°C**
?	7.00	6.13
5.5×10^{-7}	6.26	5.26
1.0×10^{-6}	6.00	5.00
5.5×10^{-6}	5.26	4.26
1.0×10^{-5}	5.00	4.00
5.5×10^{-5}	4.26	3.26
1.0×10^{-4}	4.00	3.00
5.5×10^{-4}	3.26	2.26
1.0×10^{-3}	3.00	2.00
5.5×10^{-3}	2.26	1.26
1.0×10^{-2}	2.00	1.00

i. What should go in place for the question mark (**?**) in the table (top left corner)? ***(1 point)***

ii. Using the data in the table, determine the neutral pH of water at 80˚C. ***(1 point)***

c. A member of your team proposes that a certain amount of $NaOH$ can be added to the planet's water in order to remove the strong acid you identified in your reaction in part a. This would make the water safe to drink. ***(3 points)***

Write out the reaction that occurs when these two substances are mixed, and define what type of reaction it is (ex.: redox, precipitation, acid-base, etc.). *Note: if you were not able to answer part a, use* HNO_3 *as your strong acid.*

Reaction: _____

Reaction Type: _____

Certain ions like Mg^{2+} are necessary to support any kind of life and are sourced either from water or vegetation.

d. From your team's observations, you conclude that magnesium carbonate and hydrochloric acid are present in high amounts on Planet Atomica. ***(9 points)***

    i. Write the balanced **molecular** and **net ionic** equations for the reaction between these compounds (assuming the reaction occurs in an aqueous environment and that magnesium carbonate is completely insoluble in water). ***(4 points)***

Molecular: _____

Net Ionic: _____

ii. There are 89.63 kg of solid $MgCO_3$ present in a nearby lake of 1344.45 L of 2.0 M HCl. Calculate the theoretical yield (in moles) of magnesium ions formed from this reaction, assuming the magnesium carbonate is the limiting reactant. Then calculate the theoretical concentration of magnesium ions. ***(3 points)***

Theoretical Yield (moles): _____

Theoretical Concentration (M): _____

iii. The percent yield for this reaction is 76%. What is the actual amount of magnesium ions present in moles? ***(2 points)***

Based on the highly acidic source of water, Planet Atomica could not support human life because it would harm our basic biological function. However, the presence of universally essential ions like Mg^{2+} suggests that *certain life forms* could thrive on the planet.

<u>Problem #4</u>: *(17 points)*

You and your team of space explorers would like to observe the planet's alien race, the Elementari. During your investigation, you quickly find that the aliens are able to make themselves disappear and reappear by secreting an unknown solution that covers their skin and reacts with the air. This causes their blue skin to turn invisible, then back to blue again.

a. You run a sample of the secreted solution through your ship's solution analyzer. It turns out the sample is composed of water and an unknown acid base indicator. The solution reacts with the carbon dioxide in the atmosphere to form carbonic acid, then undergoes the reaction below with its indicator component, the forward direction of which is exothermic.

Predict whether the Elementari will turn invisible for the following situations assuming that they are currently blue. Fill in the blanks with either **turn invisible** or **stay blue**. ***(3 points)***

i. The amount of carbon dioxide in the atmosphere increases.

_____

ii. Ammonia is added.

_____

iii. The temperature of the system is increased.

_____

b. You and your team want to see which acid-base indicator from Earth best matches the one in the secreted solution. You perform an experimental titration using 50.00 mL of the secreted solution and 0.100 M $NaOH$ and find that the solution changes color when 27.00 mL of $NaOH$ is added. ***(10 points)***

   i. How many moles of H_2CO_3 are in the secreted solution? ***(2 points)***

   ii. At the equivalence point, the reaction is governed by the weak base equilibrium:

$$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$$

   What is the concentration of HCO_3^- at the equivalence point of the titration? Use 0.0030 mol as the number of moles of H_2CO_3 in the secreted solution, regardless of your answer in part b(i). ***(2 points)***

iii. An ideal indicator will change colors when the reaction has reached its equivalence point. What is the pH of the reaction from part b(ii) at the equivalence point? Use 0.040 M as the initial concentration of HCO_3^-, before equilibrium has been established. The K_{a1} for carbonic acid is 4.3×10^{-7}. ***(5 points)***

iv. Using the provided table and your answer from part b(iii), which acid-base indicator from Earth best matches the indicator in the secreted solution? ***(1 point)***

Indicator	Approximate pH Range for Color Change
methyl orange	3.2–4.4
bromthymol blue	6.0–7.6
phenolphthalein	8.2–10
litmus	5.5–8.2
bromcresol green	3.8–5.4

Indicator: _____

c. You decide to make a buffer solution to mimic the secreted solution using sodium bicarbonate, $NaHCO_3$, found on your ship. How many grams of sodium bicarbonate should you add to 650 mL of 0.05 M carbonic acid to form a buffer solution with a pH = 7.00? *Reminder: the* K_{a1} *for carbonic acid is* 4.3×10^{-7}. ***(4 points)***

Problem #5: ***(19 points)***

The Elementari suddenly start attacking with laser guns! You and your team begin to retreat back to the ship.

a. The Elementari's laser beam shoots past you and strikes a nearby rock structure. The beam is comprised of a stream of electrons traveling at a speed of $4.24 \times 10^{6} \frac{m}{s}$. The lasers operate at a power of 5 W and eject 2.79×10^{18} electrons over a period of 5 seconds. Assume that for every one electron ejected, one photon is emitted. *Hint: The energy of the photons is equal to power divided by the photon rate.* ***(10 points)***

   i. Determine the wavelength of the laser's radiation (in nm). ***(3 points)***

   ii. Determine the work function of the unknown element. ***(3 points)***

iii. Based on your work in part a(ii), what is the unknown element? Circle your answer. ***(1 point)***

A. Silicon ($\boldsymbol{\phi} = 7.77 \times 10^{-19} J$)

B. Silver ($\boldsymbol{\phi} = 7.36 \times 10^{-19} J$)

C. Nitrogen ($\boldsymbol{\phi} = 7.20 \times 10^{-19} J$)

D. Aluminum ($\boldsymbol{\phi} = 6.73 \times 10^{-19} J$)

iv. Classify the unknown element as a metal, non-metal, or semimetal (metalloid), and describe **one** of that classification's important properties. ***(3 points)***

b. You and your team are finding shelter on the other side of a rock formation when you spot a field of superconducting solar panels. It seems the aliens have developed a superior energy source using a novel semiconductor that requires $8.15 \times 10^{-18} J$ to generate a current. What wavelength of light provided by the sun (in nm) would generate a current in the solar panel? ***(1 point)***

c. You collect a soil sample near the solar panels and identify the presence of four distinct elements: sulfur (S), sodium (Na), aluminum (Al), and silicon (Si). ***(8 points)***

i. Compare the properties of each element and match them to the correct element by circling your answer. *Note: you should have one element circled per row.* ***(4 points)***

- Element II has a higher **first** ionization energy than element III
- Element I has a **smaller** atomic radius than element IV
- Element III has the **second largest** electronegativity
- Element II has a **larger** electron affinity than element I

Element I:	S	Na	Al	Si
Element II:	S	Na	Al	Si
Element III:	S	Na	Al	Si
Element IV:	S	Na	Al	Si

ii. Classify each of the four elements as a nonmetal, semimetal (metalloid), or metal. ***(4 points)***

Element	Classification
S	
Si	
Al	
Na	

Problem #6: *(12 points)*

You and your team make it safely back to your ship, but you notice that a laser has punctured the ship's fuel tank causing all of the fuel to pour onto the ground. Luckily, it turns out that the Elementari's diet includes hydrazine, the compound in your fuel! Thus, they interpret your spilled rocket fuel as a calorie-rich peace offering. In exchange, the aliens agree to build you a hydrogen fuel cell to help you get home.

For the remainder of this question, assume gases behave ideally on Planet Atomica.

a. A hydrogen fuel cell works by spontaneously combining hydrogen and oxygen gas into water vapor. This electrochemical reaction is described by the following equation:

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$$

The relevant half-cell equations and standard reduction potentials are as follows:

$$2H^+(aq) + 2e^- \rightarrow H_2(g) \qquad \varepsilon^\circ = 0\,V$$

$$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l) \qquad \varepsilon^\circ = +1.23\,V$$

Calculate the Standard Cell Potential, ε°_{cell}, of the hydrogen fuel cell reaction. ***(2 points)***

b. The alien hydrogen fuel cell contains 4.0 atm of $H_2(g)$ and 1.0 atm of $O_2(g)$ and operates at a pH = 3.0 at 298 K. Calculate this cell's non-standard cell potential, using a Standard Cell Potential, $\varepsilon^{\circ}_{cell} = +2.35\,V$. ***(3 points)***

c. Calculate the volume of gaseous H_2 produced (in L) by running a current of $45.16\,A$ through the cell for 12.00 hours at $1.43\,atm$ and $24°C$. Assume all gases involved are behaving ideally. *Hint: 1 A = 1 C/s. Note: this reaction is the electrolysis of water, as in the overall reaction given in part a, but run in reverse to decompose water into hydrogen and oxygen.* ***(3 points)***

d. The aliens give you a tank of 2,000 kg of hydrogen gas, and 10,000 kg of oxygen gas. What is the maximum energy the fuel cell can generate (in Joules)? Assume that the combustion of one mole of H_2 generates 286 kJ of energy. ***(4 points)***

SCRATCH PAGE